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SHORT NOTE

Sexual Dimorphism in Soft Body Weight in Adult *Monetaria annulus* (Family Cypraeidae)

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Abstract. Sexual size dimorphism in the family Cypraeidae has been questioned due to the use of inappropriate morphometric and statistical methodologies but is demonstrated here for the first time by analysis of the soft body weight of *Monetaria annulus* (Linné, 1758) specimens collected from two distinct populations.

Cowries (Family Cypraeidae) are particularly suitable for investigating molluscan body size variation because of their stepwise shell growth. The soft body enlarges only during the juvenile stage when the shell is fragile and has a coiled structure. This is followed by the deposition of calcareous material on the surface of the juvenile shell to construct a callus. As with some other gastropods (Vermeij and Signor, 1992), cowries are determinate growers in the sense that neither soft body nor callus thickness exhibits any further increase after the callus-building stage.

A number of authors have examined whether sexual size dimorphism (SSD) exists in cowries by measuring shell length, defined as the maximum distance between the anterior and posterior shell tips of adult individuals. Statistically significant differences have been detected between the sexes in *Umbilia hesitata* (Iredale, 1916) (see Griffiths, 1961a), *Erronea errones* (see Griffiths, 1961b), and *Monetaria caputserpentis* (Linné, 1758) (see Omi and Kuramochi, 2002), but not in *Purpuradusta fimbriata* (Gmelin, 1791) (see Dayle, 1990), *Purpuradusta gracilis* (Gaskoin, 1849) (see Griffiths, 1961a), *Monetaria moneta* (Linné, 1758), *Erosaria helvola* (Linné, 1758) (see Schilder and Schilder, 1961), *Notocypraea angustata* (Gmelin, 1791) (see Griffiths, 1961b), or *Monetaria caputdraconis* (Melvill, 1888) (see Osorio et al., 1999). With regard to *M. annulus*, statistically significant SSD has been detected in one study (Katoh, 1989) but not in two others (Schilder and Schilder, 1961; Lorenz, 2000). One possible reason for such inconsistency is the pooling of specimens from a large area because, regardless of their sex, *M. annulus* can exhibit significant size differences between patches only a few dozen meters apart as the result of environmentally heterogeneous microhabitats (Irie, 2006). This is a statistical power issue, particularly when sample sizes are small. Another concern is the use of shell length as a proxy for soft body size because shell length continues to increase with the posterior callus development throughout the callus-building stage. Thus, even if shell length is statistically different between sexes, one cannot rule out the possibility that callus thickness, rather than soft body size, exhibits a sexual difference. Conversely a SSD of, for example, a larger soft body in females could be masked by a larger callus thickness in males resulting in no significant sexual difference in shell length. In order to overcome these methodological problems, the SSD in *M. annulus* was examined from two populations from Okinawa, Ryukyu-shoto, Japan.

One hundred adult *Monetaria annulus* were randomly collected from each of two 10×10 m^2 quadrats, one placed at Sesoko (N26°38′20.4″, E127°52′07.3″) on November 21, the other at Yamada (N26°26′06.0″, E127°47′09.7″) on November 23, 2006. The shell length, width, and height of each specimen were measured with calipers (Figure 1) and then the shell was broken and removed from the soft body with tweezers, including all fragments. After determining the sex, the soft body was dried by heating for 2 hr at 100°C in a dehydrator and then weighed. The sex ratio did not significantly differ from 1:1 in either Yamada (45 females, 55 males; binomial test, $P = 0.315$) or Sesoko (48 females, 52 males; $P = 0.764$). Mean dry weights (± population standard deviation) were 0.598 g (±0.082) for females and 0.535 (±0.081) for males in Yamada and 0.678 (±0.103) for females and 0.646 (±0.090) for males in Sesoko (Figure 2A).

For each location, data for male and female dry weight were standardized according to their respective z-scores and then pooled. The dry weight was not

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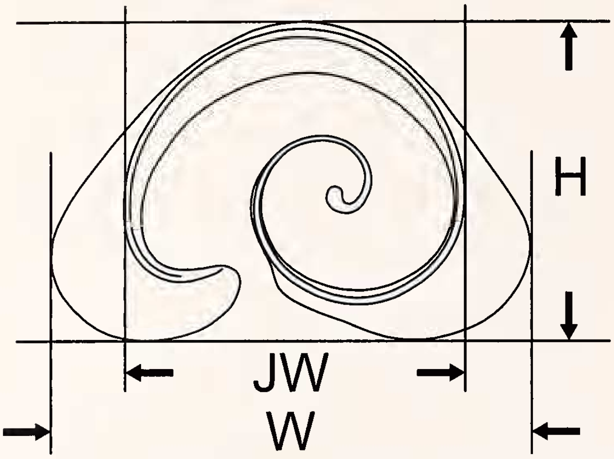

Figure 1. Cross-section of the shell of adult *Monetaria annulus*. Abbreviations: W, adult shell width; H, adult shell height; JW, juvenile shell width.

found to be normally distributed in either Yamada (Shapiro-Wilk test, $W = 0.933$, $P < 10^{-4}$) or Sesoko ($W = 0.943$, $P < 0.001$). However, weight is expected to scale with volume and the cube root of dry weight was found to be normally distributed in both Yamada ($W = 0.983$, $P > 0.05$) and Sesoko ($W = 0.975$, $P > 0.05$). Subsequent parametric tests were conducted on the cube root of dry weight, simply referred to as "dry weight" in the following analysis. The data were divided into four groups according to sex and location. In order to assess the homogeneity of variance, the absolute deviation from the group mean was calculated for each datum. Two-factor crossed ANOVA on the absolute deviation with sex and locality as fixed effects indicated that the variance was positively correlated to the mean between localities ($P = 0.012$). After applying a logarithmic transform to ensure homogeneity of variance (Sokal and Rohlf, 1995), two-factor crossed ANOVA on the dry weight showed that both locality and sex had significant effects (locality, $P < 10^{-11}$; sex, $P < 0.001$) but the locality × sex interaction did not ($P > 0.05$). Although dry body weight is the most reliable indicator of sexual size dimorphism, for comparison adult shell length was also analyzed. Two-factor crossed ANOVA indicated that females have significantly larger shells. Locality and sex both had significant effects (locality, $P < 10^{-17}$; sex, $P < 0.01$) but the locality × sex interaction did not ($P > 0.05$). In order to examine the relationship between soft body weight and juvenile shell size, the juvenile shell width (JW; Figure 1) was estimated from the adult shell width (W) and height (H) using an allometric equation proposed by Irie (2006). The correlation (r) between dry weight and estimated JW was 0.891, significantly different from zero ($P < 10^{-15}$). The relative callus

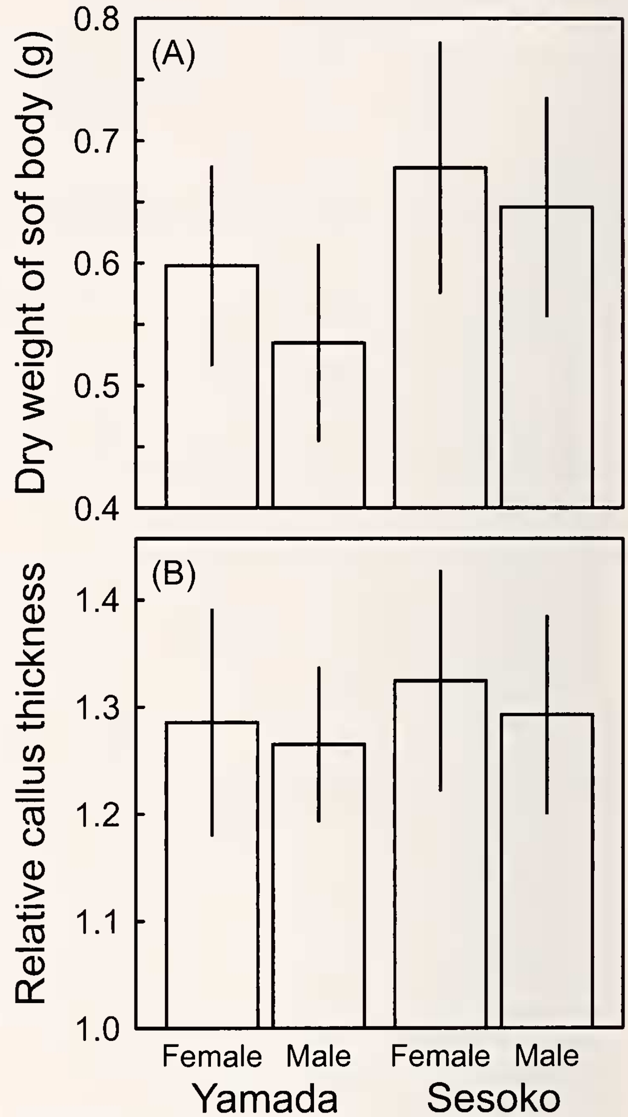

Figure 2. (A) Dry weight of soft body and (B) relative callus thickness (RCT), calculated as shell width/estimated juvenile shell width (W/JW), of the female and male *Monetaria annulus* collected from Yamada and Sesoko coasts of Okinawa, Ryukyu-Soto, Japan. Error bars indicate standard deviations.

thickness (RCT) of each individual, W/JW, was also calculated. This was preferred to the absolute callus thickness, W – JW, because it cancels the effect of overall size differences among individuals. Mean RCT was larger in females than males in both localities (Figure 2B). Two-factor crossed ANOVA on RCT indicated that the effect of locality was significant ($P = 0.014$), the effect of sex was marginally non-significant ($P = 0.051$) and the effect of the locality × sex interaction was not significant ($P > 0.05$).

In conclusion, *Monetaria annulus* exhibits sexual size dimorphism such that females have a larger soft body than males. The difference in relative callus thickness between males and females was not found to be significant, though only marginally, and this SSD could also be detected from adult shell length. Thus SSD in *Monetaria annulus* is probably not masked by callus size but can easily be masked by environmentally determined size variation when specimens from several distinct areas are pooled.

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